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STUDY OF CORPUSCULAR RADIATION ON SPACECRAFT "LUNA-10"

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SUMMARY

This paper presents the detailed measurement data on cosmic radiations registered aborad the first AMS "LUNA-10". As such, this paper is an "in extenso" version of an earlier note (ST-LPS-PF-10 528) and also (ST-LPS-CR-10 526), where the description of the apparatus was given. *

The intensity of primary cosmic radiation in interplanetary space is determined. The albedo for the primary radiation relative to lunar surface has been measured in the orbit of the AMS. Data have been obtained on the fluxes of soft corpusuclar radiation in the region of the tail of the Earth's magnetosphere, upholding the preliminary conclusions that have been previously communicated.

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The wide range of questions connected with the dynamics of the flow by corpuscular streams past the Earth's magnetosphere and with the processes in transitional regions, where these fluxes interact with the Earth's magnetosphere and where acceleration of particles possibly takes place, put forward, alongside with the problem of the study of the low-energy part of solar cosmic ray spectrum, specific requirements and impositions to the flight trajectory of spacecraft destined to investigate them. These spacecrafts must be located, most of the time, at a certain optimum distance from the Earth, beyond the magnetosphere. LUNA-10 fully satisfies these conditions, and this is why it has been equipped with an apparatus capable of measuring the intensity of primary cosmic rays and of low-energy particles of the "soft" corpuscular radiation.

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* (Note by Translator). This is not entirely a cover-to-cover translation. Some parts, such as the description of apparatus, have been deleted, since they were already the object of treatment in the above-mentioned preliminary notes.

The prolonged measurements of radiation intensity conducted on LUNA-10 while it moved along an ellitpical orbit, allowed us to measure with great precision the intensity of cosmic rays at various distances from the lunar surface and to obtain a specific information on the emission characteristics of the albedo, measured by S. N. Vernov et al on LUNA-9 [1].

Moreover, owing to Moon's rotation around the Earth, the prolonged measurements aboard LUNA-10, an AMS, allow in principle to ascertain the question of Earth's magnetosphere influence on the spatial distribution of soft corpuscular radiation intensity over ranges from the Earth of the order of 60 R_E.

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APPARATUS

[The reader is referred to the previous papers ST— 10 526 and 528].

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*   *

MEASUREMENTS OF COSMIC RAYS

The counter, schielded from all sides by a brass screen, registered the primary cosmic radiation. The counting rate measurement by the shielded counter in free space was conducted between 31 March and 3 April 1966.over a portion of the trajectory Earth-Moon. The observations were conducted during three sessions of about 1.5 hour duration. The mean counting rate of the shieldede counter was $n = 12.2 \pm 0.06$ sec^{-1}. The counting rate, measured every two-minute interval, differed from the mean counting rate by no more than 3 percent. Therefore, the absolute value of the primary cosmic radiation constituted ± 4.7 ± 0.4 cm^{-2} sec^{-1}. The measured value of the flux shows that despite the increase of solar activity toward the summer of 1966, the intensity of primary radiation continued to remain sufficiently high. The value of the flux, brought out, practically coincides with the data obtained on LUNA-9 two months prior to the current experiment [1].

On 3 April 1966 LUNA-10 was brought into a selenocentrical orbit with aposelion 1000 km and periselion 350 km, the inclination angle to the Moon's equatorial plane being 72°. Beginning from that moment, measurements were conducted to 29 May at various moments of time corresponding to varioues ranges of the satellite from the lunar surface. Altogether 79 sessions of cosmic ray intensity measurements were conducted for the indicated time interval. The result of measurements were broken down into groups corresponding to an altitude interval $\Delta h \approx 100$ km.

Determined within the bounds of each group was the mean intensity, corresponding to the intensity I(h) of radiation for the given range h of the satellite fron the lunar surface. The dependence I(h) is plotted in Fig.I.

The dependence of the counting rate I of the shielded counter on h arises from the shielding by the Moon of a part of space, which hinders the arrival of cosmic ray particles from it into the counter. If $\Omega(h)$ is the solid angle at which the Moon is seen from a point, remote from the lunar surface by a distance h, n_0 is the intensity of cosmic rays per unit of solid angle and S is the area of the counter, we have

$$I(h) = n_0 S 4\pi - n_0 S \Omega(h) = n_0 S\, 4\pi \left[1 - \frac{\Omega(h)}{4\pi}\right]$$

as $4\pi n_0 S = I_\infty$, where I_∞ is the counting rate by the shielded counter in interplanetary space ($h \to \infty$), we have

$$\frac{I(h)}{I_\infty} = 1 - \frac{\Omega(h)}{4\pi}, \qquad \Omega(h) = 2\pi\left[1 - \frac{\sqrt{1+2R_л/h}}{1+R_л/h}\right] \qquad (1)$$

where $R_л$ is the radius of the Moon.

If the lunar surface is the source of albedo having an isotropic angular distribution and the intensity an_0, it is easy to show that

$$\frac{I(h)}{I_\infty} = 1 - (1-a)\frac{\Omega(h)}{4\pi}.$$

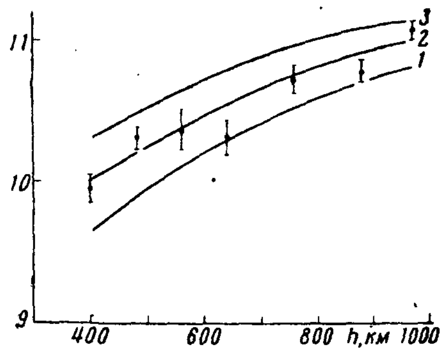

Fig.1. Counting rate of the shielded counter as a function of height above the surface of the Noon (dots)

The curves are computed in the assumption of albedo a = 0 (curve 1), a = 0.13 (curve 2), and a = 0.25 (curve 3)

Besides experimental points, we plotted in Fig.1 three theoretical curves, computed in the assumption that a = 0, a = 0.13 and a = 0.25. We took for I_∞ the value obtained by us, which is $I_\infty = 12.2\ \text{sec}^{-1}$

From the comparison of the computed curves with the experimental dependence I(h) it may be seen that the value a = 0.13 agrees well with the data of the experiment. In ot other words, it follows from our experiment that the intensity of albedo radiation constitutes ~13% of the intensity of cosmic rays.

In the work [1], the value of albedo radiation intensity was 26% of cosmic ray intensity. This discrepancy is legitimate and it can be explained by the fact that this radiation, mainly constituting electrons of cascade showers having scattered in the surface layer of lunar ground over large angles, is partially absorbed in the brass filter surrounding the counter. The mean effective thickness of the filter is 5.1 g/cm . Electrons with energies to 8 Mev may pass through that screen. The decrease in the intensity of albedo radiation from 26 to 13 percent, that is,by a factor of 2, by a filter, absorbing electrons with energies to 8 Mev, provides the estimate for the lower value of critical energy β of lunar surface matter, equal to 28 Mev. This estimate has been obtained in the assumption that the albedo radiation has an equilibrium spectrum (see [2]). Such a value corresponds to a substance with atomic weight 17 [2] or 24, if one uses the values of cascade units from the work [3]. As we already noted above, the albedo emission consists of electrons having scattered over large angles ($\gtrsim$ radian), that is, from the "softest" part of the equilibrium spectrum. Thus, for the entire equilibrium spectrum the absorption in 5.1 g/cm would be less than the factor of 2, and this is why the true value is > 28 Mev, and correspondingly, the effective value of the atomic number of lunar surface matter is

$$Z_{eff} \lesssim 17 \div 24.$$

"SOFT" CORPUSCULAR RADIATION

The end-window counter with the unshielded mica window could register electrons with energy $\gtrsim$40 kev and electrons with energy $\gtrsim$500 kev, that is, aside from cosmic rays, constituting its background, it measured a comparatively soft corpuscular radiation.

The results of measurements by this counter show that the counting rate did not remain constant during the entire measurement period. Substantial intensity increases were observed, exceeding at times the background level by 10-20 times.

Fig.2 shows the results of measurements over a portion of trajectory between the Earth and the Moon. During that period the spacecraft was not oriented and the axis of the counter changed its position in space. The sharp periodic counting rate increases are apparently linked with the variation of counter's axis orientation relative to the directed radiation fluxes.

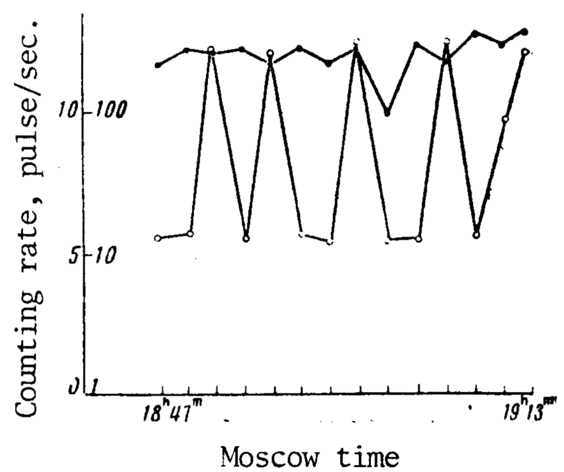

Fig.2. Readings of the shielded (black circles, linear scale along the vertical) and unshielded (clear circles, logarithmic scale along the vertical) counters over the portion of trajectory of 2 April 1966

In the AMS orbit LUNA-10 spinned around a longitudinal axis coinciding with the axis of the unshielded counter's collimator. The axis of ritation was somewhat inclined to the orbit plane of the satellite, constituting with the direction at the Sun an angle >90° With such an orientation, and taking into account the position of the counters on LUNA-10 surface, the unschielded counter could not possibly register the Sun's X-ray radiation. The small variation of the counting rate when the satellite hits the shadow of the Moon is an additional confirmation of that fact, when it is compared with the counting rate outside the shadow. On 3 May at 0040 hours the satellite was in the Moon's shadow, and at 0145 hours at was on the sunny side of the Moon. In the first case the unshielded counter registered 14 pulses/sec (in periselion) and in the second case it registered 16 pulses/sec (in aposelion), while the mean level of background for that counter was 11.2 ±0.1 pulses/sec. (with ~3% measurement precision).

The difference in intensities of 1 pulse/sec is caused by the variation of cosmic background when passing from aposelion to periselion. Thus, the increased intensity observed on 3 May does not depend on satellite illumination by the Sun, i. e., it cannot be ascribed to the registration of Sun's X-ray radiation. For that reason the variation of the counting rate of the nonshielded counter should be ascribed to the appearance of charged particles of low energy (these particles did not induce any increase in the counting rate of the shielded counter). The variations in the intensity of soft radiation, observed during the two months of operation of the instrument package, are compiled in the Table and in Figures 3, a, b.

Attention is drawn by the fact that from 3 to 23 April an increased counting rate of low-energy particles (relative to cosmic background level) was registered, whereupon the counting rate attained a maximum on 9 April and decreased monotonically, reaching by about 23 April the background level, conditioned by primary cosmic rays.

Beginning from 25 April and up to 27 April the nonshielded counter had all the time (with the exception of a region to which it will be referred below) a counting rate corresponding to the registration of cosmic radiation.

From 27 to 29 May the appearance of soft corpuscular radiation was again revealed during 6 measurement sessions. Because the energy resources of the probe were at that time exhausted, measurements of 29 May were the last ones.

The low energy particle fluxes registered from 3 to 23 April and from 27 to 29 May 1966 may be quite naturally linked with the appearance of comparatively quiet forms of solar activity, insufficient to induce intense fluxes of solar protons and electrons. Inasmuch as the period from 2 to 9 April is characterized by a comparatively high activity of the Sun in the radioband, and the period from 9 to 14 April — by increased level of disturbances of terrestrial ionosphere, it is possible that one kind of particles (electrons with energy $\gtrsim$ 40 kev) were registered from 2 to 9 April, and another kind (protons with energy $\gtrsim$500 kev) — from 9 to 14 April.

Particular interest is offered by the short-lived increases in the intensity of soft radiation registered by us on 4, 9 April and 3 May (see Fig.3, a, b and the Table). Besides, the intensity rises on 2 - 4 May were registered by an analogous apparatus of S. L. Mandel'shtam, installed on LUNA-10 [4]. (On 4 and 9 April the Mandel'shtam apparatus was not switched on).

These increases are characteristic by the fact that they are comparatively short-lived and correspond to about the region of the extension of the Earth's magnetosphere tail.

It is possible that these intensity increases are caused by the intersection of the Earth's magnetosphere tail and are evidence that in the boundary layer of the magnetosphere tail there exists a quasi-steady flux of low-energy particles.

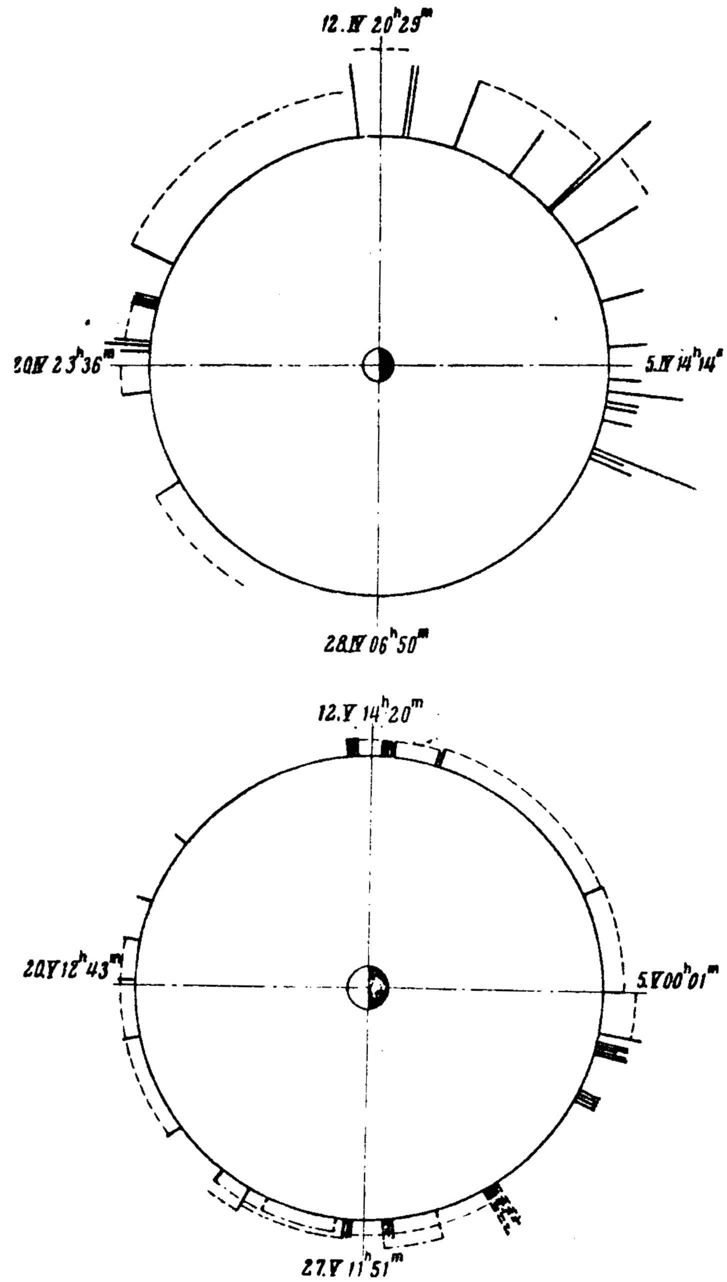

Fig.3. Readings of the unshielded counter as a function of the position of the satellite relative to the lines Sun - Earth

The Sun is to the left. The height of solid radial lines corresponds to the counting rate during the session- The dashed arcs indicate the mean values of the counting rate between sessions. The dashed radial lines and the dash-dotted arcs (b) correspond to measurements during the second passage by the Moon of this region of angles. The numerals give the times of passage by the Moon of the given point: a) for the period 3-25 Apr.; b) for that 25 Ap.to 29 May. (Moscow Time)

TABLE

Date of measurement 1966	Beginning and end of measurement	(min.) Measurement Interv.	Counting rate pulse/ /sec^{-1}	Angle ϕ Sun-Earth- - Moon; deg.
03.IV	21^h56^m—22^h00^m	4	30	—157
	23 23 —23 55	32	24	—158
04	01 34 —01 46	12	80	—160
	18 39 —18 43	4	21	—169
	18 45 —20 01	76	25	—169,5
	20 01 —20 33	32	22	—170
	23 14 —23 18	4	20	—171,5
05	04 14 —04 22	8	50	—174,3
	19 35 —21 05	90	21	177
06	00 37 —00 41	4	25	174,7
	23 00 —23 08	8	29	162
08	04 57 —05 31	34	50	147
08	05 31	1214	60	
09	—01 47			137
09	01 47 —02 17	30	110	
	02 23 —02 51	28	70	
	02 51 —03 25	34	50	136
	03 25	1430	53	
10	—03 16			124
	03 16 —03 20	4	38	
10	03 20	1686	54	
11	—07 26			109
	07 26 —08 00	34	50	109
12	06 56 —07 10	14	50	97
	07 10 —07 52	42	50	
	07 52 —07 56	4	50	
12	08 36	1260	62	96
13	—04 36			86
	06 47 —08 11	84	53	84,5
13	08 18	7500	32	
18	—13 18			26
18	13 35	1440	30	
19	—13 35			15
	13 36 —13 48	12	18	
	13 48 —14 32	36	19	
	14 22 —14 30	8	20	
	14 32 —15 12	40	19	
	15 14 —16 20	66	20	14
	16 20 —16 32	18	19	
19	16 38	932	15	
20	—08 50			6
20	08 14 —08 58	44	25	
	09 10 —10 56	106	20	5
	10 56 —11 12	16	22	
	11 12 —11 56	44	22	
	11 56 —12 52	56	32	4
	12 52 —13 26	34	26	
20	13 26 —	1480	20	3
21	—14 06			—7
	14 07 —14 41	34	20	
23	12 01 —12 11	10	18	—31
23	12 12 —	3540	18	—62
25	—23 12			
25	23 22 —	2706	13	
27	—20 26			—85
	20 26 —20 40	14	12	
	20 40 —21 32	52	13	
	21 32 —23 32	120	13	—86
27	23 32	1070	10,7	
28	—17 22			—95,5
	17 22 —17 34	12	11,7	
	13 20 —18 30	10	11,7	—96

TABLE (continued)

Date of measurement 1966	Beginning and end of measurement	Measurement Interval (min.)	Counting rate pulse/ /sec^{-1}	Angle ϕ Sun - Earth- - Moon. (deg.)
	18^h30^m--20^h40^m	130	11,7	
28.IV	20 40	5950	12	—97
02.V	--23 50			—153
02	23 50 —00 00	10	16	
03	00 00 --00 40	40	15,5	
	00 40 --00 52	12	14	
	00 52 --01 46	54	14	
	01 46 --01 56	10	16	—154
	21 14 --21 22	8	24	
	21 22 --22 08	46	22	—165
	22 08 --22 14	6	14	
	23 02 —23 10	8	21	
	23 10 —23 56	46	21	--166
03	23 56 —	12	30	
04	—00 08			
	00 08 —23 26	1398	23	
04	23 26 —	44	13	180
05	—00 10			
05	00 10 —	3080	14	
07	—03 30			154,5
07	03 36	5885	13	
11	—05 41			106
	05 41 —05 53	12	11	
	05 53 —06 31	37	11	
11	06 31 —	1370	11	
12	—05 21			94
	05 21 —05 33	12	11,3	
	05 33 —06 51	78	11,3	
	06 51 —07 03	12	10,5	
	09 01 —09 35	34	11,3	92
17	08 35 —10 05	90	11,2	37
	11 40 —11 52	12	10,7	
	11 52 —13 15	83	11,5	
18	16 26 —16 32	6	10,9	21
19	12 50 —12 56	6	10,7	11
20	11 05 —	1506	10,7	1
21	—12 11			
21	12 11 —	1400	11	—13
23	—11 27			—38
	11 27 —11 39	12	11,7	
24	14 36 —14 46	10	11,7	—40
24	14 16 —14 24	8	11,3	—52,5
25	14 24 —	1443	11	
25	—14 27			—65
26	14 33 —	1773	10,8	
26	—20 06			—82
27	20 10 —20 07	6	20	—95
27	20 07	1434	19	
28	—20 01			—108
29	20 01 —20 07	6	36	
	20 09 —20 23	14	32	—121
	20 23 —21 12	29	25	
	21 12 —21 26	14	22	
	21 26 —22 07	41	37	
	22 07 —22 19	12	38	—122
	22 19 —23 11	52	36	
	23 11 —23 25	14	53	—123

End of the Table

It was shown during the flight of the second Soviet cosmic rocket in September 1959 that at distances >1000 km from the surface of the Moon the intensity of the penetrating radiation, trapped by the magnetic field of the Moon, is zero within the limits of measurement precision [5]. However, the instrument package of the 2nd cosmic rocket could not register protons with energy ~ 0.5 Mev, whereas electrons with energy ~ 40 kev could be detected only by their bremmstrahlung, and with insignificant effectiveness. Measurements of the upper limit of intensity for electron fluxes with energies $\gtrsim 40$ kev are of interest; these, as is shown by fairly simple calculations, could be retained by a permanent magnetic field of the Moon of $\sim 10 \div 20\gamma$ magnitude, the existence of which is not excluded by the available magnetic measurements.

Provided it is used during a long measurement time, the apparatus installed by us aboard LUNA-10 allowed us to establish reliably the intensity limit of electron fluxes with energies $\gtrsim 40$ kev. During a substantial part of measurement time from 27 April to 2 May and from 11 to 25 May (see Table) the unshielded counter registered 11.2 pulses/sec as an average. Since the relative effective geometric factor for the penetrating radiation through a unshielded counter constituted, according to ground measurements, 0.95 ± 0.05 of the geometric factor of a shielded counter, the average counting rate of which near the Moon constituted $10.5\ \mathrm{sec}^{-1}$, we obtain for this measurement period the upper estimate of the intensity of fluxes

$$\frac{11.2\ \mathrm{sec}^{-1} - (0.95 - 0.005)\cdot 10.5\ \mathrm{sec}^{-1}}{0.4\ \mathrm{cm}^2\cdot \mathrm{sterad}} \approx 3\ \mathrm{cm}^{-2}\ \mathrm{sterad}^{-1}\cdot \mathrm{sec}^{-1},$$

where $0.4\ \mathrm{cm}^2 \cdot$sterad is the geometric factor of an unshielded counter for the soft radiation.

Therefore, if there exists a radiation, constantly trapped by the magnetic field of the Moon at altitudes from 350 to 1000 km from the lunar surface, the fluxes of electrons with energies 40 kev do not exceed $3\ \mathrm{cm}^{-3}\cdot \mathrm{sterad}^{-1}\cdot \mathrm{sec}^{-1}$.

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